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6.2 Piles

During 2008 and 2009 three related research projects on Load and Resistance Factor Design (LRFD) of driven piles are being conducted by Iowa State University. As a temporary measure, until the research is complete, the Iowa pile charts have been calibrated to LRFD in 2007 and are included in Article 6.2.7. As the charts are temporary and there is not a great need for metric computations, the charts and associated examples are entirely in English units.

6.2.1 General

Piles directly support bridge substructure components and other transportation-related structures. In addition to the information in this series of articles the designer should review the information for specific bridge substructure components: abutments [BDM 6.5] and piers [BDM 6.6].

6.2.1.1 Policy overview

The office designs piles for downward load, downdrag, and uplift by the load and resistance factor design (LRFD) method modified for use with the 2007 LRFD geotechnical resistance charts provided in a subsequent article [BDM 6.2.7].

Of the available pile types, the office most often specifies steel H-piles because of the capacities and lengths required for support of substructure components. For typical design conditions the office requires the HP 10x57 (HP 250x85) shape when using steel H-piles for integral abutments for pretensioned prestressed concrete beam (PPCB) and continuous welded plate girder (CWPG) bridges [BDM 6.5.1.1.1]. When using steel H-piles for integral abutments for continuous concrete slab (CCS) and rolled steel beam (RSB) bridges and for support of other substructure components the office prefers the HP 10x42 (HP

250x62) shape. To avoid construction errors the office prefers that only one of the two HP-10 (HP-250) shapes be used on a project.

For relatively short bridges where site conditions permit, the designer is encouraged to consider timber piles. For site conditions that favor displacement piles and also for pile bents without fully encased piles the designer is encouraged to consider prestressed concrete piles. Pile choices for typical substructure components are summarized in Table 6.2.1.1.

Table 6.2.1.1. Pile choices for support of substructure components

Substructure Component	Pile Choices
Integral abutment	Steel HP 10x57 (HP 250x85) for PPCB and CWPG bridges, HP 10x42 (HP 250x62) for CCS and RSB bridges; timber for bridge lengths to 200 feet (61.000 m)
Stub abutment	Steel HP; timber; 12 inch (310 mm) prestressed concrete
Pier	Steel HP; timber; 12 inch (310 mm) prestressed concrete, steel pipe
Pile bent [OBS SS P10A]	Steel HP; 14 or 16 inch (356 or 406 mm) prestressed concrete, 14 or 16 inch (356 or 406 mm) steel pipe

On most Iowa bridge sites, piles derive their load-supporting capacity from friction and end bearing. In cases where piles bear on rock they shall be driven to seat into the rock a distance recommended by the Soils Design Section.

The office also designs piles for lateral loading by LRFD. For relatively light loading the designer may use assumed nominal resistances given in subsequent articles [BDM 6.2.6.1, 6.2.6.3] or, for greater capacities, the designer may perform an analysis with consideration of soil, pile material, cross section, deflection, and strength criteria.

6.2.1.2 Design information

The soils design package provided for each bridge site by the Soils Design Section contains the soil logs needed for pile design [BDM 6.1.2], and the preliminary situation plan locates the borings. When the section recommends pile foundations, design of the piles shall be in accordance with the 2007 LRFD geotechnical resistance charts [BDM 6.2.7].

For specification, material, or construction information beyond the information in this manual and the soils information chart [BDM 6.2.1.5], the designer should consult the following sources. The most up-to-date versions of the publications are available on the Iowa Department of Transportation web site in the Electronic Reference Library (http://www.erl.dot.state.ia.us), except as noted.

- Office of Specifications, *Standard Specifications for Highway and Bridge Construction, Series 2001*, Articles 2501, 4165, 4166, and 4167
- Office of Materials, Instructional Memoranda, 467 and 467.02
- Office of Construction, *Construction Manual*
- Office of Construction, *New Bridge Construction Handbook* (http://www.iowadot.gov/construction/structures/bridge_construction_handbook.pdf)

6.2.1.3 Definitions

Natural ground elevation is the average natural ground elevation along the longitudinal centerline of the foundation.

6.2.1.4 Abbreviations and notation

CCS, continuous concrete slab
CMP, corrugated metal pipe
CWPG, continuous welded plate girder

LRFD, load and resistance factor design
MSE, mechanically stabilized earth
N or N-value, standard penetration test number of blows per foot (300 mm). N also may be given as **SPT NO,** the Standard Penetration Test Number, in the soils information chart reference. Unless otherwise noted these values are uncorrected.
PPCB, pretensioned prestressed concrete beam
RSB, rolled steel beam
SRL, structural resistance level. Numbered levels are defined in the H-pile article [BDM 6.2.6.1].
$\Sigma \eta_i \gamma_i P_i \leq \varphi \Sigma p_{ni} L_i + \varphi f_n A + \varphi P_n$**,** LRFD geotechnical check for a timber, steel H, prestressed concrete, or steel pipe pile. Individual variables are defined in a subsequent article [BDM 6.2.4.1].
$\Sigma \eta_i \gamma_i P_i \leq n \varphi_c P_n$**,** LRFD structural check in the ground for a steel H-pile. Individual variables are defined in a subsequent article [BDM 6.2.6.1].
$\Sigma \eta_i \gamma_i P_i \leq n \varphi P_n$**,** LRFD structural check in the ground for a timber pile. Individual variables are defined in a subsequent article [BDM 6.2.6.3].

6.2.1.5 References

Dirks, Kermit and Patrick Kam. *Foundation Soils Information Chart, Pile Foundation*. Ames: Iowa Department of Transportation, Office of Road Design, January 1989/September 1994. (Contact the Soils Design Section of the Office of Design for a copy of the publication. For LRFD, use the updated 2007 LRFD geotechnical resistance charts in this manual [BDM 6.2.7].)

GAI Consultants, Inc. *The Steel Pile, Pile Cap Connection.* Washington, DC: American Iron and Steel Institute (AISI). 1982. (Contact AISI for a reprint, for which there is a charge.)

Office of Construction. *Construction Manual.* Ames: Office of Construction, Iowa Department of Transportation, 2008. (Available on the Internet at: http://www.iowadot.gov/erl/current/CM/Navigation/nav.pdf)

Office of Materials. *Pile Points for Steel H-Piles, Instructional Memorandum 468.* Ames: Office of Materials, Iowa Department of Transportation, 2008. (Available on the Internet at: http://www.iowadot.gov/erl/current/IM/Navigation/nav.pdf)

Office of Materials. *Steel H-Piles, Instructional Memorandum 467.01.* Ames: Office of Materials, Iowa Department of Transportation, 2008. (Available on the Internet at: http://www.iowadot.gov/erl/current/IM/Navigation/nav.pdf)

Office of Materials. *Steel Piles, Instructional Memorandum 467.* Ames: Office of Materials, Iowa Department of Transportation, 2009. (Available on the Internet at: http://www.iowadot.gov/erl/current/IM/Navigation/nav.pdf)

Sunday, Wayne and Kyle Frame. *New Bridge Construction Handbook.* Ames: Office of Construction, Iowa Department of Transportation, 2000. (Available on the Internet at: http://www.iowadot.gov/construction/structures/bridge_construction_handbook.pdf)

6.2.2 Loads

Pile loads must be considered with respect to the substructure component supported by the piles. Abutment and pier articles [BDM 6.5 and 6.6] cover additional load topics, and the designer should review those articles in addition to the articles below.

For standard abutment, footing, and pile cap details the office assumes axial vertical loads transmitted to piles. If nonstandard pile head details cause significant eccentricity or moment, the designer shall consider those effects in design.

When lateral loads are applied to piles the designer shall consider both forces and displacements [BDM 6.2.4.5].

6.2.2.1 Dynamic load allowance [AASHTO-LRFD 3.6.2.1]

The AASHTO LRFD Specifications [AASHTO-LRFD 3.6.2.1] note that the dynamic load allowance (IM) need not be applied to foundation components entirely below ground level. As a conservative design simplification, the office requires the designer to include the dynamic load allowance for the entire length of a pile that has a portion unsupported by soil, such as a pile in a pile bent or an integral abutment pile in a prebored hole filled with bentonite slurry.

However, the designer shall not include the dynamic load allowance on a stub abutment pile in a prebored hole. Because scour generally is a temporary condition the designer also should not include dynamic load allowance on a pile being checked under scour conditions.

6.2.2.2 Downdrag

For soils that are labeled compressible in the soils package for the bridge project, the designer shall consider downdrag forces caused by negative skin friction on vertical piles. Battered piles shall not be used if downdrag will occur. Downdrag forces add to the pile loads through negative skin friction if time is not allowed for the consolidation delay sometimes required for abutment berms.

Downdrag forces shall be determined from the 2007 LRFD geotechnical resistance charts in accordance with policy in a subsequent article [BDM 6.2.4.3].

6.2.3 Load application

6.2.3.1 Load modifier [AASHTO-LRFD 1.3.2, 3.4.1]

Load factors shall be adjusted by the load modifier, which accounts for ductility, redundancy, and operational importance [AASHTO-LRFD 1.3.2, 3.4.1]. For typical pile foundations the load modifier shall be taken as 1.0.

6.2.3.2 Limit states [AASHTO-LRFD 3.4.1, 3.4.2]

For a typical pile foundation, the designer shall consider the following load combinations for the supported structural component, as applicable [AASHTO-LRFD 3.4.1]. For design of abutment foundations the designer should use judgment to exclude any combinations that will not control.

- Strength I, superstructure with vehicles but without wind
- Strength III, superstructure with wind exceeding 55 mph (89 kph)
- Strength V, superstructure with vehicles and wind at 55 mph (89 kph)
- Extreme Event II, superstructure with reduced vehicles and vehicular collision, ice, or hydraulic events
- Service I, superstructure with vehicles and wind at 55 mph (89 kph)

In general the designer need not investigate Service I limit state unless settlement, lateral movement, or overall stability is a concern.

Except for unusual situations, such as eccentric loads during staged construction, the designer need not investigate construction load combinations [AASHTO-LRFD 3.4.2].

Design of the pile foundation shall be based on the resulting critical combinations for maximum axial force, maximum moment, and maximum shear.

6.2.4 Analysis and design

Pile section and length shall be determined by the load and resistance factor design (LRFD) method as modified in this and other manual sections, considering structural capacity, geotechnical capacity, and drivability.

- **Structural capacity:** To determine the required pile section and/or number of piles for typical pier and abutment design, the designer shall compare the factored axial load per pile or per pile group with the factored structural resistance. Specific guidelines for structural design by pile type are given in a subsequent article [BDM 6.2.6], and guidelines for integral abutment piles are given in the abutment section [BDM 6.5.1.1.1]. Piles that extend above ground such as those in pile bents also need to be checked structurally for the column condition using the guidelines given in this manual [BDM 6.6.4.2]. Piles subject to scour need to be checked for the column condition below the footing [BDM 6.6.4.1.3.1].

- **Geotechnical capacity:** To determine the required pile length the designer shall compare the factored axial load per pile with the factored geotechnical resistance determined from the 2007 charts [BDM 6.2.4.2]. Additional guidelines are given below [BDM 6.2.4.1]. Piles subject to scour need to be checked for the loss of soil support [BDM 6.6.4.1.3.1].
- **Drivability:** The designer also shall consider drivability as indicated in the guidelines by pile type [BDM 6.2.6].

6.2.4.1 General [AASHTO-LRFD 10.7.1.2, 10.7.1.3]

In addition to the basic geotechnical resistance check [BDM 6.2.4.2], pile length will depend on various site and substructure factors. The design penetration for any pile should be a minimum of 10 feet (3.050 m) in hard cohesive or dense granular soil and a minimum of 20 feet (6.100 m) in soft cohesive or loose granular soil. Piles driven through embankments should penetrate 10 feet (3.050 m) into original ground unless refusal on bedrock or a competent layer occurs at a lesser elevation [AASHTO-LRFD 10.7.1.3].

In order to relieve stresses due to lateral movement, piles for integral abutments for bridges longer than 130 feet (39.600 m) shall be driven in prebored holes. Abutment piles also may be driven in prebored holes to reduce downdrag due to settlement of the abutment berm. Prebored hole depths are given in Table 6.2.4.1.

Table 6.2.4.1. Prebored hole depths for abutments

Abutment type	Hole depth feet (m)	Comments
Integral	10 (3.048) (1)	Standard depth
Integral	15 (4.572)	Maximum depth without approval of supervising Section Leader
Stub	20 (6.096)	Maximum depth without approval of supervising Section Leader

Table note:

(1) If bedrock is less than 15 feet from bottom of footing, prebored hole depth may be reduced with consideration of bridge length, but the designer shall discuss the condition with the supervising Section Leader.

Pile length shall be determined so that the geotechnical resistance due to friction, end bearing, or a combination of friction and end bearing will be achieved below the lowest of the following elevations:

- Bottom of predrilled hole (abutments) [BDM Tables 6.2.4.1, 6.5.1.1.1-1, and 6.5.1.1.1-2],
- Bottom of pile encasement (pile bents) [BDM 6.6.4.2.2],
- Bottom of compressible fill when berm consolidation delays are not permissible,
- Design scour elevation (piers) [BDM 6.6.4.1.3.1], or
- Check scour elevation (piers) [BDM 6.6.4.1.3.1].

Additional considerations for determining the pile length are the following.

- Natural or original ground elevation is the average natural ground elevation along the longitudinal centerline of the foundation.
- Heads of piles shall be embedded in abutments, footings, bent caps, and pier caps the length given in the pile detailing article [BDM 6.2.5].
- The heads of steel H-piles, steel pipe piles, and timber piles shall be trimmed one foot (305 mm) to account for driving damage.

- If fill is placed above a compressible soil layer, such as at an abutment, piles will be subjected to downdrag forces.
- The bentonite slurry [IDOT SS 2501.03, Q] required for filling of a prebored hole for a pile shall be assumed to provide no vertical or lateral support to the pile. The slurry also shall be assumed to cause no downdrag forces.
- A pile battered no more than 1 horizontal to 4 vertical may be assumed to carry the same vertical load as a pile driven vertically; there need be no reduction for angle of the pile.
- If several pile types or sizes are feasible, the designer should discuss the alternatives with the supervising Section Leader. Determining the best or most economical alternative involves pile availability and cost, driving equipment availability and cost, and structural factors.

For steel H-piles and timber piles, length shall be specified to the nearest 5-foot (1.500-m) increment. For prestressed concrete piles, length shall be specified to the nearest 1-foot (305 mm) increment, except that pile extensions shall be specified to the nearest 5-foot (1.500 m) increment.

Maximum centerline pile spacing shall be 8 feet (2.440 m), and minimum centerline pile spacing shall be the larger of 2.5 feet (760 mm) or 2.5 times the pile size [AASHTO LRFD 10.7.1.2]. Based on soil conditions and additional rules below, piles shall be spaced at a centerline distance that does not exceed the maximum or minimum limits. The minimum centerline distance to a footing edge shall be 1.5 feet (460 mm).

When a mechanically stabilized earth (MSE) retaining wall is placed in front of integral abutment piles, the piles typically are sleeved with corrugated metal pipe (CMP). For compaction of the fill between the sleeves and placement of the metal strip reinforcing for the wall, a minimum sleeve clear distance of 24 inches (600 mm) is preferred. With the typical 24-inch (600-mm) diameter CMP and a 24-inch clear distance, the centerline pile spacing will be 4 feet (1.220 m). Therefore, the designer needs to consider the minimum pile spacing carefully for integral abutments behind MSE walls.

For integral abutments the office also requires a minimum 36 inches (900 mm) clear between the MSE wall and the CMP sleeves. The clearance is intended to permit compaction of the backfill, to avoid sharp angles in the reinforcing straps, and to prevent the bentonite in the CMP sleeves from freezing. For stub abutments the clear distance may be less than 36 inches (900 mm) subject to requirements of the MSE wall vendor. When the MSE wall is built in two stages and/or when utility lines are in the backfill zone the designer shall determine clearances based on discussions with the MSE wall vendor.

The minimum number of piles for an integral abutment shall be one pile per beam plus one pile per wing extension.

For integral abutments the office requires that all piles be driven vertically, but for all other substructure elements the designer should batter some of the piles as indicated on standard sheets. Typically the front row and wing wall piles for stub abutments, the perimeter piles for pier footings, and the end piles for pile bents should be battered. The preferred batter for stub abutments and piers is 1 horizontal to 4 vertical, with 1 to 6 as an acceptable alternative, and the preferred batter for pile bents is 1 horizontal to 12 vertical. The designer shall check battered piles for interference with temporary structures such as cofferdams, as well as utility lines and foundations.

For pier foundations subject to scour, the designer shall check unsupported length and size of pile according to the appropriate pier and pile bent footing guidelines [BDM 6.6.4.1.3.1, 6.6.4.2.1].

For each foundation the designer should attempt to use the minimum number of piles required for structural support. Individual pile layouts for each foundation are preferred, and the designer should not add extra piles to replicate foundations.

6.2.4.2 Downward load

Pile length for downward load shall be determined by using the 2007 LRFD geotechnical resistance charts [BDM 6.2.7] and the basic check given below. Depending on subsurface conditions, the pile resistance may be the

- accumulated skin friction resistance through several soil layers,
- the end bearing resistance at rock, or
- the accumulated skin friction resistance plus end bearing resistance at rock or a dense soil layer.

$$\Sigma\eta_i\gamma_iP_i \leq \varphi\Sigma p_{ni}L_i + \varphi f_nA \text{ or } \varphi P_n$$

$\Sigma\eta_i\gamma_iP_i$ = total factored axial load per pile determined by usual LRFD procedures for a strength limit state, kips

$\varphi\Sigma p_{ni}L_i$ = total factored friction resistance for a steel, timber, or concrete pile

φ = 0.725 (calibrated for average load factor of 1.45)

p_{ni} = nominal pile friction resistance for a specific soil layer, if applicable, taken from the 2007 LRFD geotechnical resistance chart for friction pile, kips/foot [BDM 6.2.7]

L_i = length of pile in a specific soil layer, feet

φf_nA = factored end bearing resistance for a steel H-pile

f_n = nominal end bearing resistance for H-pile, if applicable, taken from the 2007 LRFD geotechnical resistance chart for end bearing pile, ksi [BDM 6.2.7]

A = cross section area of H-pile, in^2

φP_n = total factored end bearing resistance for a timber, prestressed concrete, or steel pipe pile

P_n = nominal end bearing resistance for timber, prestressed concrete, or steel pipe pile, if applicable, taken from the 2007 LRFD geotechnical resistance chart for end bearing pile, kips [BDM 6.2.7]

See the commentary for background discussion [BDM C6.2.4.2] and steel H-pile Examples (1) and (2) [BDM C6.2.6.1].

6.2.4.3 Downdrag

In cases where vertical piles will be subjected to downdrag the designer shall include the factored downdrag load at the strength limit state in the pile design. The downdrag load shall be determined from the 2007 LRFD geotechnical resistance chart for friction piles, and the load factor shall be taken as 1.0.

As per CADD Note E833/M833 [BDM 11.8.2] the plans shall note the service limit state values of the following:

- Theoretical driving resistance
- Resistance in and above compressible layers
- Resistance for downdrag, and
- Resistance for design load.

See the commentary for background discussion [BDM C6.2.4.3] and steel H-pile Example (3) [BDM C6.2.6.1].

6.2.4.4 Uplift

Under all limit states the designer may consider uplift on piles provided that piles are sufficiently anchored in the footing and have sufficient soil-to-pile friction resistance for the uplift force. Bond resistance between footing concrete and an H-pile and resistance factors are discussed in the steel H-pile article [BDM 6.2.6.1].

See the commentary for background discussion [BDM C6.2.4.4] and steel H-pile Examples (4) and (5) [BDM C6.2.6.1].

6.2.4.5 Lateral load [AASHTO-LRFD 10.7.2.4]

For typical bridge piers and stub abutments supported on steel H-piles or timber piles the designer may check lateral loading of piles at the service and strength limit states using assumed nominal resistances given in following articles [BDM 6.2.6.1, 6.2.6.3]. Piles in typical integral abutments need not be checked for lateral load.

If the checks using nominal values fail or if the pile conditions require further analysis, the office prefers that the designer use the program LPILE or equivalent software to check deflection at the service limit state and moment and shear at the strength and extreme event limit state. Group effects shall be considered [AASHTO-LRFD 10.7.2.4].

If using LPILE to check pier or stub abutment piles for typical bridges, the designer may assume a maximum service limit state lateral deflection of 0.25 inch (6 mm) for a single pile or 0.75 inch (19 mm) for a pile group. Lateral deflection at the top of a pier should be limited to 1.50 inches. If these limits are exceeded the designer shall consult with the supervising Section Leader.

See the commentary for background discussion [BDM C6.2.4.5] and steel H-pile Examples (6), (7), and (8) [BDM C6.2.6.1].

6.2.5 Detailing

Piles shall be embedded in substructure elements and shall have the head reinforcing listed in Table 6.2.5.

Table 6.2.5. Minimum pile embedment and pile head reinforcing

Substructure element	**Minimum embedment**	**Pile head reinforcing**
Integral abutment for A or B pretensioned prestressed concrete beams (PPCBs)	2 feet (600 mm)	Spiral (1)
Integral abutment for C, D, BTB, BTC, BTD, or BTE pretensioned prestressed concrete beams (PPCBs)	2 feet (600 mm)	Spiral (1) and bent p bars (2)
Integral abutment for steel plate girders	2 feet (600 mm)	Spiral (1) (3) and bent p bars (2) (3)
Stub abutment on timber piles	2 feet (600 mm)	Spiral (3)
Stub abutment on steel piles	2 feet (600 mm)	None (4)
Pier footing	1 foot (300 mm)	None (3)
Continuous concrete slab pile bent cap (not monolithic with slab)	1.5 feet (460 mm)	None (3)
Continuous concrete slab pile bent cap (monolithic with slab)	1 foot (300 mm)	Cap steel (bent dowels) (5)

Table notes:

(1) Spiral is placed around each pile head as detailed on standard sheets [OBS SS 2078-2091]. The spiral should not be epoxy coated.

(2) For the bent p bars see the Abutment Pile Plan on standard sheets [OBS SS 2085-2091].

(3) No standard sheet is available.
(4) See standard sheets for C or D beams [OBS SS 2092-2105].
(5) Cap steel (bent dowels) is detailed on a standard sheet [OBS SS P10L].

For pier footings with reinforcing placed directly above H-pile, pipe pile, or timber pile heads, plans shall include a note requiring that all battered piles be trimmed to a horizontal line to aid in placement of reinforcement. Prestressed concrete piles should not be trimmed.

Plans shall state the service limit state bearing for piles in tons (kN). See standard CADD Notes for piers E720 (M720) and for abutments E820 (M820) [BDM 11.8.2]. Because the number of piles typically is rounded up to the next whole pile, the service limit state bearing to be given in the note usually will be less than the maximum plan sheet bearing [BDM Table 6.2.6.1-1 for H-piles].

For projects for which downdrag forces are included in the pile design, the E833 (M833) CADD Note [BDM 11.8.2] shall be included on the plans.

For projects involving the Excavate and Dewater bid item the E832 (M832) CADD Note [BDM 11.8.2] shall be included on the plans.

6.2.6 Guidelines by pile type

For information on selecting pile type for integral abutments see the guidelines in the integral abutment article [BDM 6.5.4.1.1].

6.2.6.1 Steel H [AASHTO-LRFD 6.5.4.2, 10.5.5.3.3]

Steel H-piles are feasible in most Iowa soils and may attain geotechnical resistance through end bearing, friction, or a combination of end bearing and friction.

Steel H-piles shall be of material meeting ASTM A 572/A 572M Grade 50 (345) [IDOT SS 4167.01, A, OM IM 467.01], unless an exception is approved by the supervising Section Leader.

The basic structural check for typical integral abutment, stub abutment, and pier H-piles is given below. The check represents an axial force condition at the bottom of a pile, with consideration of the potential for driving damage.

$$\Sigma \eta_i \gamma_i P_i \le n \varphi_c P_n$$

$\Sigma \eta_i \gamma_i P_i$ = total factored axial load per pile or per pile group determined by usual AASHTO LRFD procedures for a strength limit state, kips

n = number of piles

φ_c = 0.6 for normal driving. For unusually severe driving conditions requiring driving points the Soils Design Section may recommend φ_c = 0.5 [AASHTO-LRFD 6.5.4.2].

P_n = nominal pile structural resistance at the strength limit state, kips. Structural resistances for H-piles are given in Table 6.2.6.1-1.

See the commentary for additional discussion [BDM C6.2.4.2] and steel H-pile Examples (1) and (2) [BDM C6.2.6.1].

In order to fit LRFD H-pile design for downward loads to previous practice under the AASHTO Standard Specifications, three Structural Resistance Levels (SRLs) are defined as follows.

- Structural Resistance Level – 1 (SRL-1) is the resistance based on an average load factor, γ, of 1.45, an allowable stress of 6 ksi (41 MPa), and a resistance factor, φ_c, of 0.6. This resistance level is intended to limit settlement. SRL-1 shall be used for abutment or pier piles with the following conditions.

- H-piles that tip out in soil and are designed for friction only.
- H-piles that tip out in soil and are designed for friction and end bearing.
- H-piles that are driven into rock and are designed for end bearing on rock with an N of 100 to 200.

- Structural Resistance Level – 2 (SRL-2) is the resistance based on an average load factor, γ, of 1.45, an allowable stress of 9 ksi (62 MPa), and a resistance factor, φ_c, of 0.6. SRL-2 shall be used for abutment or pier piles with the following conditions.
  - H-piles that are driven into rock and are designed for end bearing on rock with an N greater than 200.
  - H-piles that tip out in soils with relatively high N-values and are designed for end bearing or a combination of friction and end bearing, with approval of the Soils Design Section.
  - H-piles that are driven into rock and are designed for a combination of friction and end bearing on rock with an N of 100 to 200, with approval of the Soils Design Section.

- Structural Resistance Level -- 3 (SRL-3) is the resistance based on an average load factor, γ, of 1.45, an allowable stress of 12 ksi (83 MPa), and a resistance factor, φ_c, of 0.6. SRL-3 shall be used only for pier piles with the following conditions.
  - H-piles that are driven into rock and are designed for end bearing on rock with an N greater than 200, with drivability analysis during design and with approvals of the Soils Design Section and the Assistant Bridge Engineer.
  - H-piles that are driven into rock and are designed for a combination of friction and end bearing on rock with an N greater than 200, with drivability analysis during design and with approvals of the Soils Design Section and the Assistant Bridge Engineer.

At the three SRLs Table 6.2.6.1-1 gives the nominal resistances and maximum plan sheet bearing values for typical H-pile sections. Higher loads may be permissible if bearing is verified by a pile load test. The plans for a specific bridge shall state the actual required bearing, as with CADD Notes E720 (M720) and E820 (M820) [BDM 11.8.2]. Because the number of piles typically is rounded up, the actual required bearing to be given on the plans often will be less than the maximum value in Table 6.2.6.1-1.

Table 6.2.6.1-1. Nominal structural resistance and maximum plan sheet bearing for typical Grade 50 H-piles [(1)]

H-pile section	Structural Resistance Level – 1		Structural Resistance Level - 2		Structural Resistance Level - 3	
	Nominal resistance, P_n, kips (kN) [(2) (5)]	Max. plan sheet bearing, tons (kN)	Nominal resistance, P_n, kips (kN) [(3) (5)]	Max. plan sheet bearing, tons (kN)	Nominal resistance, P_n, kips (kN) [(4) (5)]	Max. plan sheet bearing, tons (kN)
HP 10x42 (HP 250x62)	179 (796)	37 (330)	269 (1196)	55 (496)	359 (1596)	74 (661)
HP 10x57 (HP 250x85)	243 (1080)	50 (448)	365 (1623)	75 (672)	487 (2166)	100 (896)
HP 12x53 (HP 310x79) [(6)]	224 (996)	46 (413)	337 (1499)	69 (620)	449 (1997)	93 (827)
HP 14x73 (HP 360x108) [(6)]	310 (1378)	64 (571)	465 (2068)	96 (856)	620 (2757)	128 (1142)
HP 14x117 (HP 360x174)	498 (2215)	103 (918)	748 (3327)	154 (1377)	997 (4434)	206 (1836)

Table notes:

(1) The designer may select H-pile sections not given in the table but shall check availability for those sections.
(2) These values were calculated from 1.45*6 ksi*A/0.6, which simplifies to 14.50*A or f_nA, (and then were converted to metric).
(3) These values were calculated from 1.45*9 ksi*A/0.6, which simplifies to 21.75*A or f_nA, (and then were converted to metric).
(4) These values were calculated from 1.45*12 ksi*A/0.6, which simplifies to 29.00*A or f_nA, (and then were converted to metric).
(5) If the Soils Design Section recommends $\varphi_c = 0.5$, these tabulated values should not be increased because the intent of the lower φ_c is to increase the number of piles.
(6) Because of slender flanges these sections are not to be used for integral abutments.

In unusual cases where piles are subjected to significant moment or eccentric load or where piles extend above ground such as in a pile bent [BDM 6.6.4.2] the piles also need to be checked structurally at or near their tops. Piles subject to scour need to be checked structurally as columns below footings [BDM 6.6.4.1.3.1].

The geotechnical design to determine pile length shall follow the procedures in this manual [BDM 6.2.4].

In cases where piles are projected to achieve sufficient geotechnical resistance within 5 feet (1.524 m) of bedrock the designer should consider driving the piles to rock.

Steel H-piles driven to bedrock should penetrate the surface of the rock to depths recommended by the Soils Design Section, which generally are given in the soils information chart [BDM 6.2.1.5].

The designer should consider using approved driving points [OM IM No. 468] if H-piles must be driven through soil layers containing boulders or if piles must be driven into sloping rock surfaces. Verify the need for driving points with the Soils Design Section. If points are needed include on the plans CADD Note E722 or E821 [BDM 11.8.2], whichever is appropriate.

Although the LRFD specifications require reduction of the structural resistance factor, φ_c, to 0.50 when pile points are used [AASHTO-LRFD 6.5.4.2] the factor will be subject to judgment of the Soils Design

Section. Unless the Soils Design Section recommends the lower resistance factor the designer shall use a structural resistance factor of 0.6.

For steel H-piles the total driving resistance at the service limit state shall not exceed the force that would cause a stress of 12 ksi (83 MPa). If the driving resistance at the service limit state exceeds the force that would cause 9 ksi (62 MPa) the designer shall request a wave equation analysis for the piles from the Office of Construction.

For checking uplift on a steel H-pile embedded in a concrete footing, the designer shall use a nominal bond resistance of 0.060 ksi (0.41 MPa) and $\varphi = 0.45$. If bond is insufficient for the factored load the designer shall consult with the supervising Section Leader. The preferred alternative is to resize the footing, but another alternative is to anchor the pile head with shear studs or other positive anchorage devices such as those described in *The Steel Pile, Pile Cap Connection* [BDM 6.2.1.5].

For checking uplift on a steel H-pile embedded in soil, the designer shall determine the pile resistance from the 2007 LRFD soils information chart for friction, neglecting any soil that may be lost due to scour or other site degradation. The designer shall apply a resistance factor $\varphi_{up} = 0.60$ for uplift at the strength limit state and $\varphi_{up} = 0.80$ for uplift at the extreme event limit state [AASHTO-LRFD 10.5.5.3.3].

In the absence of special analysis the designer may assume the lateral resistances given in Table 6.2.6.1-2.

Table 6.2.6.1-2. Nominal assumed lateral resistance per H-pile

Service limit state resistance (1)	Strength or extreme event limit state resistance (1)
6 kips (27 kN)	18 kips (80 kN)

Table notes:
(1) The designer may add the horizontal component of the resistance of a battered pile.

Examples are included in the commentary for this article [BDM C6.2.6.1] for downward load, downdrag, uplift, and lateral load.

6.2.6.2 Concrete-filled steel pipe

In general, concrete-filled steel pipe piles are not economical for typical Iowa bridges and have been used only at contractor request as a substitution for steel H-piles.

Steel pipe piles shall be of material meeting ASTM A 252 Grade 2 or Grade 3 [IDOT SS 4167.01, B, OM IM 467.03], unless an exception is approved by the supervising Section Leader.

The structural design to determine the concrete-filled steel pipe pile section shall follow the AASHTO LRFD Specifications, and the geotechnical design to determine pile length shall follow the procedures in this manual [BDM 6.2.4]. Pipe piles should not be driven in soils with consistent N-values greater than 40.

Driving points may be needed for pipe piles in some soil conditions. The designer shall verify the need for driving points with the Soils Design Section.

6.2.6.3 Timber [AASHTO-LRFD 8.4.1.3, 8.4.4, 8.5.2.2]

Timber piles are considered feasible only in soils with N-values of 25 or less. Timber piles shall not be used in soils that contain boulders, and timber piles for support of bridge substructure components shall not be used for bearing on rock.

Timber piles for permanent foundations shall be treated and shall meet the requirements in the standard specifications [IDOT SS 4165].

The basic structural check for typical integral abutment [BDM 6.5.1.1.1], stub abutment, and pier piles is given below. The check represents an axial force condition at the tip of a pile. In unusual cases where the top of a pile extends above ground or is subjected to significant moment or eccentric load, the pile also needs to be checked structurally at or near its top.

$$\Sigma\eta_i\gamma_iP_i \leq n\varphi P_n$$

$\Sigma\eta_i\gamma_iP_i$ = total factored axial load per pile or per pile group determined by usual AASHTO LRFD procedures for a strength limit state, kips

n = number of piles

φ = 0.9 for compression parallel to grain [AASHTO-LRFD 8.5.2.2].

P_n = nominal pile structural resistance at the strength limit state, kips, determined from reference design value [AASHTO-LRFD Table 8.4.1.3-1], adjustment factors [AASHTO-LRFD 8.4.4], and tip area [IDOT SS 4165.03, H]. Tip area is directly related to specified minimum tip diameter, which is related to pile length. Therefore, it may be necessary to determine pile length with a geotechnical check discussed below before beginning the structural check or even before beginning abutment or pier design.

See the commentary for timber pile Examples (1) and (2) [BDM C6.2.6.3].

In fitting past office practice under the AASHTO Standard Specifications to LRFD to determine maximum nominal geotechnical resistance, the office has used an average load factor, γ, of 1.45 and a resistance factor, φ, of 0.725. For stub abutments and piers the maximum nominal geotechnical resistance shall be 80 kips (355 kN) for piles 20 to 30 feet (6.100 to 9.150 m) long and 100 kips (444 kN) for piles 35 to 55 feet (10.670 to 16.760 m) long. The minimum pile length shall be 20 feet (6.100 m), and the maximum pile length shall be 55 feet (16.760 m), with intermediate lengths in 5-foot (1.500-m) increments.

Because of indeterminate bending stresses, for integral abutments the maximum nominal axial structural resistance for a timber pile shall be 64 kips (286 kN) which, due to the difference in structural and geotechnical resistance factors, will give the same limit as a maximum nominal geotechnical resistance of 80 kips (355 kN).

Although the maximum nominal geotechnical resistance values given above can provide guidance for preliminary design, the designer shall use the procedures in this manual [BDM 6.2.4] to verify that the maximum can be achieved for a specific substructure component or to determine a lesser resistance.

To provide a pinned head condition for timber piles in integral abutments where the bridge length is 150 feet to less than 200 feet (45.700 to less than 61.000 m), the pile heads shall be wrapped with carpet (or rug) padding. See the commentary for details and plan note [BDM C6.2.6.3].

For large projects with 1500 feet (457 m) or more of timber piles and especially when piles tip out in soft material with N-values of 10 or less, the designer should consider requiring a test pile or a pile load test and shall discuss the issue with the supervising Section Leader. A test pile or a pile load test should be located in a relatively dry abutment or pier footing but not in a prebored hole or in a cofferdam.

Timber piles have limited overcapacity for hard driving and thus should not be used for projects that will subject piles to significant downdrag forces.

Timber piles should be fitted with metal driving shoes only when recommended by the Soils Design Section. Figure 6.2.6.3-1 gives the driving shoe detail for timber piles less than 40 feet (12.190 m) in length, and Figure 6.2.6.3-2 gives the detail for piles 40 to 55 feet (12.190 to 16.760 m) in length.

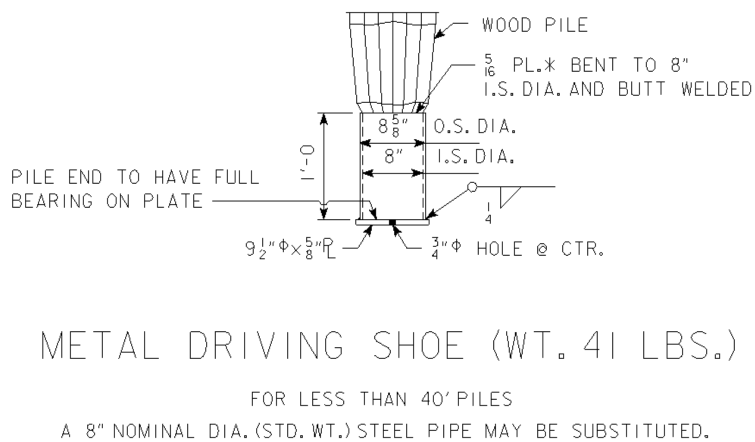

Figure 6.2.6.3-1. Metal driving shoe for timber piles less than 40 feet (12.190 m) in length

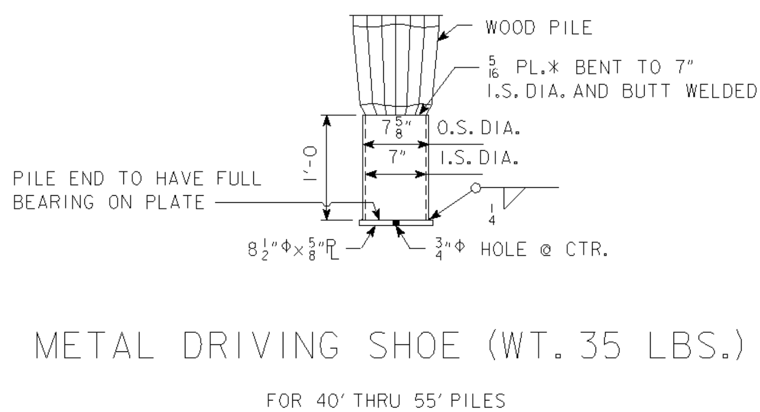

Figure 6.2.6.3-2. Metal driving shoe for timber piles 40 to 55 feet (12.190 to 16.760 m) in length

In the absence of special analysis the designer may assume the lateral resistances given in Table 6.2.6.3.

Table 6.2.6.3. Nominal assumed lateral resistance per timber pile

Service limit state resistance (1)	Strength or extreme event limit state resistance (1)
4 kips (18 kN)	7 kips (31 kN)

Table notes:

(1) The designer may add the horizontal component of the resistance of a battered pile.

6.2.6.4 Prestressed concrete

Prestressed concrete piles are feasible only in soils that permit displacement piles and soils that provide adequate geotechnical resistance through friction or a combination of friction and end bearing. Prestressed piles have proven to be difficult to drive in very firm glacial clay and very firm sandy glacial clay, and the designer shall consult with the Soils Design Section before using prestressed piles in those soils. Prestressed concrete piles should not be driven in glacial clay with consistent N-values greater than 30 to 35. The soil layer at the tip of the pile shall have an N-value in the 25 to 35 range, with no boulders.

Prestressed concrete bearing piles shall meet the material, strength, and other requirements of the standard specifications [IDOT SS 2407].

The designer may consider 12-inch (310-mm) square prestressed concrete piles for support of piers and stub abutments but not for integral abutments [OBS SS 1046]. Prestressed concrete piles 14 or 16 inches (360 or 410 mm) square are an option for pile bents as detailed and noted on the standard sheet for trestle pile bents [OBS SS P10A].

The structural design for 12-inch (310-mm) square piles detailed on the standard sheet [OBS SS 1046] shall follow the AASHTO LRFD specifications. The maximum nominal structural resistance to be used in design shall be 200 kips (900 kN).

The geotechnical design to determine pile length shall follow the procedures in this manual [BDM 6.2.4].

The maximum length of an individual 12-inch (310 mm) foundation pile section shall be 55 feet (16.760 m). When piles longer than 55 feet (16.760 m) are required, pile splices shall be used to fasten pile sections together. Only one splice will be allowed for overall pile lengths in the 56 to 110-foot (17.070 to 33.500 m) range. Pile sections shall be welded together at the splice after the first section is driven.

Standard sheets [OBS SS 1046] require a steel splice plate on the driving end of the pile. Pile suppliers can be expected to provide 5-foot (1.525-m) and 10-foot (3.050-m) extensions for splicing a pile that does not achieve required bearing at the expected depth.

The designer shall consult with the Soils Design Section regarding the need for steel driving points.

Top portions of 12 inch (310 mm) prestressed concrete piles to be embedded in stub abutment or pier footing concrete shall be roughened, after driving, by sandblasting or other approved methods to improve bond between piles and footing [OBS SS 1046 and IDOT SS 2403.03, I].

6.2.7 Geotechnical resistance charts

The following charts give nominal geotechnical resistance values for end bearing and friction piles. These 2007 LRFD charts have been extrapolated from the 1994 charts by removing the presumed safety factor of two and by converting units from tons or pounds to the kip units used in the AASHTO LRFD Specifications. Thus most values in these LRFD charts are four times the values in the 1994 charts. The charts also were modified for written statements in *Foundation Soils Information Chart, Pile Foundation* and past office practice for timber and prestressed concrete piles.

LRFD DRIVEN PILE FOUNDATION GEOTECHNICAL RESISTANCE CHART, ENGLISH UNITS

SOIL DESCRIPTION	BLOW COUNT N-VALUE		ESTIMATED NOMINAL RESISTANCE VALUES FOR END BEARING PILE IN KIPS [KSI]										
			WOOD PILE (1), (3)	STEEL "H" GRADE 50			PRESTRESSED CONCRETE (2)			STEEL PIPE (4)			
	MEAN	RANGE		10	12	14	12	14	16	10	12	14	18
Granular material													
	<15	---	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)
Fine or medium sand	15	---	32	(5)	(5)	(5)	60	84	108	32	48	64	108
Coarse sand	20	---	44	(5)	(5)	(5)	84	116	148	44	64	88	144
Gravelly sand	21	---	44	(5)	(5)	(5)	84	116	148	44	64	88	144
	25	---	56	(5)	(5)	(5)	(7)	(7)	(7)	(7)	(7)	(7)	(7)
	---	25-50	(6)	[2-4]	[2-4]	[2-4]	(6), (7)	(6), (7)	(6), (7)	(7)	(7)	(7)	(7)
	---	50-100	(6)	[4-8]	[4-8]	[4-8]	(6)	(6)	(6)	(7)	(7)	(7)	(7)
	---	100-300	(6)	[8-16]	[8-16]	[8-16]	(6)	(6)	(6)	(7)	(7)	(7)	(7)
	---	>300	(6)	[18]	[18]	[18]	(6)	(6)	(6)	(7)	(7)	(7)	(7)
Bedrock													
	---	100-200	(6)	[12]	[12]	[12]	(6)	(6)	(6)	(7)	(7)	(7)	(7)
	---	>200	(6)	[18]	[18]	[18]	(6)	(6)	(6)	(7)	(7)	(7)	(7)
Cohesive material													
	12	10-50	16	(5)	(5)	(5)	28	40	52	16	24	32	52
	20	---	24	[1]	[1]	[1]	44	64	84	28	36	52	84
	25	---	32	[2]	[2]	[2]	60	84	108	32	48	64	108
	50	---	(6)	[4]	[4]	[4]	116 (6)	164 (6)	212 (6)	56	96	128	212
	100	---	(6)	[7]	[7]	[7]	(6)	(6)	(6)	(6)	(6)	(6)	(6)

Table notes:

(1) Wood piles shall not be driven through soils with N > 25.

(2) With prestressed concrete piles the preferred N for soil at the tip ranges from 25 to 35. Prestressed concrete piles have been proven to be difficult to drive in very firm glacial clay and very firm sandy glacial clay. Prestressed concrete piles should not be driven in glacial clay with consistent N > 30 to 35.

(3) End bearing resistance values for wood piles are based on a tip area of 72 in^2. Values shall be adjusted for a different tip area.

(4) Steel pipe piles should not be driven in soils with consistent N > 40. See the 1994 soils information chart [BDM 6.2.1.5] for end bearing when a conical driving point is used.

(5) Do not consider end bearing.

(6) Use of end bearing is not recommended for timber piles when N > 25 or for prestressed concrete piles when N > 35 or for any condition identified with this note.

(7) End bearing resistance shall be 0.0389 x "N" value [ksi].

LRFD DRIVEN PILE FOUNDATION GEOTECHNICAL RESISTANCE CHART, ENGLISH UNITS													
SOIL DESCRIPTION	**BLOW COUNT**		**ESTIMATED NOMINAL RESISTANCE VALUES FOR FRICTION PILE IN KIPS/FOOT**										
	N-VALUE		**WOOD PILE**	**STEEL “H” GRADE 50**			**PRESTRESSED CONCRETE**			**STEEL PIPE**			
	MEAN	**RANGE**		**10**	**12**	**14**	**12**	**14**	**16**	**10**	**12**	**14**	**18**
Alluvium or Loess													
Very soft silty clay	1	0 - 1	0.8	0.4	0.8	0.8	0.8	0.8	0.8	0.4	0.4	0.4	0.8
Soft silty clay	3	2 - 4	1.2	0.8	1.2	1.2	0.8	0.8	0.8	0.8	0.8	0.8	1.2
Stiff silty clay	6	4 - 8	1.6	1.2	1.6	2.0	1.2	1.6	2.0	1.2	1.2	1.6	2.0
Firm silty clay	11	7 - 15	2.4	2.0	2.4	2.8	2.4	2.8	3.2	1.6	2.0	2.4	2.8
Stiff silt	6	3 - 7	1.6	1.2	1.6	1.6	1.6	1.6	1.6	1.2	1.2	1.6	1.6
Stiff sandy silt	6	4 - 8	1.6	1.2	1.6	1.6	1.6	1.6	1.6	1.2	1.2	1.6	1.6
Stiff sandy clay	6	4 - 8	1.6	1.2	1.6	2.0	2.0	2.0	2.4	1.2	1.6	1.6	2.0
Silty sand	8	3 - 13	1.2	1.2	1.2	1.6	1.6	1.6	1.6	0.8	0.8	1.2	1.6
Clayey sand	13	6 - 20	2.0	1.6	2.0	2.8	2.4	2.4	2.8	1.6	2.0	2.4	2.8
Fine sand	15	8 - 22	2.4	2.0	2.4	2.8	2.4	2.8	3.2	1.6	2.0	2.4	2.8
Coarse sand	20	12 - 28	3.2	2.8	3.2	3.6	3.2	3.6	4.0	2.0	2.4	2.8	3.6
Gravely sand	21	11 - 31	3.2	2.8	3.2	3.6	3.6	3.6	4.0	2.0	2.4	2.8	3.6
Granular material	> 40	---	(2)	4.0	4.8	5.6	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Glacial Clay													
Firm silty glacial clay	11	7 - 15	2.8	2.4	2.8	3.2	2.8	3.2	3.6	2.0	2.4	2.4	3.2
Firm clay (gumbotil)	12	9 - 15	2.8	2.4	2.8	3.2	2.8	3.2	3.6	2.0	2.4	2.4	3.2
Firm glacial clay(1)	11	7 - 15	2.4 [3.2]	2.8 [3.2]	3.2 [4.0]	3.6 [4.4]	3.2 [4.0]	3.6 [4.4]	4.0 [4.8]	2.0 [2.4]	2.4 [2.8]	2.8 [3.2]	3.6 [4.4]
Firm sandy glacial clay(1)	13	9 - 15	2.4 [3.2]	2.8 [3.2]	3.2 [4.0]	3.6 [4.4]	3.2 [4.0]	3.6 [4.4]	4.0 [4.8]	2.0 [2.4]	2.4 [2.8]	2.8 [3.2]	3.6 [4.4]
Firm - very firm glacial clay(1)	14	11 - 17	2.8 [3.6]	2.8 [4.0]	3.2 [4.8]	3.6 [5.6]	4.0 [4.8]	4.4 [5.2]	4.8 [5.6]	2.4 [3.2]	2.8 [3.6]	3.2 [4.0]	4.0 [5.2]
Very firm glacial clay(1)	24	17 - 30	2.8 [3.6]	2.8 [4.0]	3.2 [4.8]	3.6 [5.6]	3.2 (3) [4.8]	3.6 (3) [5.6]	4.4 (3) [6.4]	2.4 [3.2]	2.8 [3.6]	3.2 [4.0]	4.0 [5.2]
Very firm sandy glacial clay(1)	25	15 - 30	3.2 [4.0]	2.8 [4.0]	3.2 [4.8]	3.6 [5.6]	3.2 (3) [4.8]	3.6 (3) [5.6]	4.4 (3) [6.4]	2.4 [3.2]	2.8 [3.6]	3.2 [4.0]	4.0 [5.2]
Cohesive or glacial material(1)	> 35	---	(2)	2.8 [4.0]	3.2 [4.8]	3.6 [5.6]	(2)	(2)	(2)	2.0 (4) [3.2]	2.4 (4) [4.0]	2.8 (4) [4.4]	3.6 (4) [5.6]

Table notes:

(1) For double entries the upper value is for an embedded pile within 30 feet of the natural ground elevation, and the lower value [ ] is for pile depths more than 30 feet below the natural ground elevation.
(2) Do not consider use of this pile type for this soil condition, wood with N > 25, prestressed concrete with N > 35, or steel pipe with N > 40.
(3) Prestressed concrete piles have proven to be difficult to drive in these soils. Prestressed piles should not be driven in glacial clay with consistent N > 30 to 35.
(4) Steel pipe piles should not be driven in soils with consistent N > 40.